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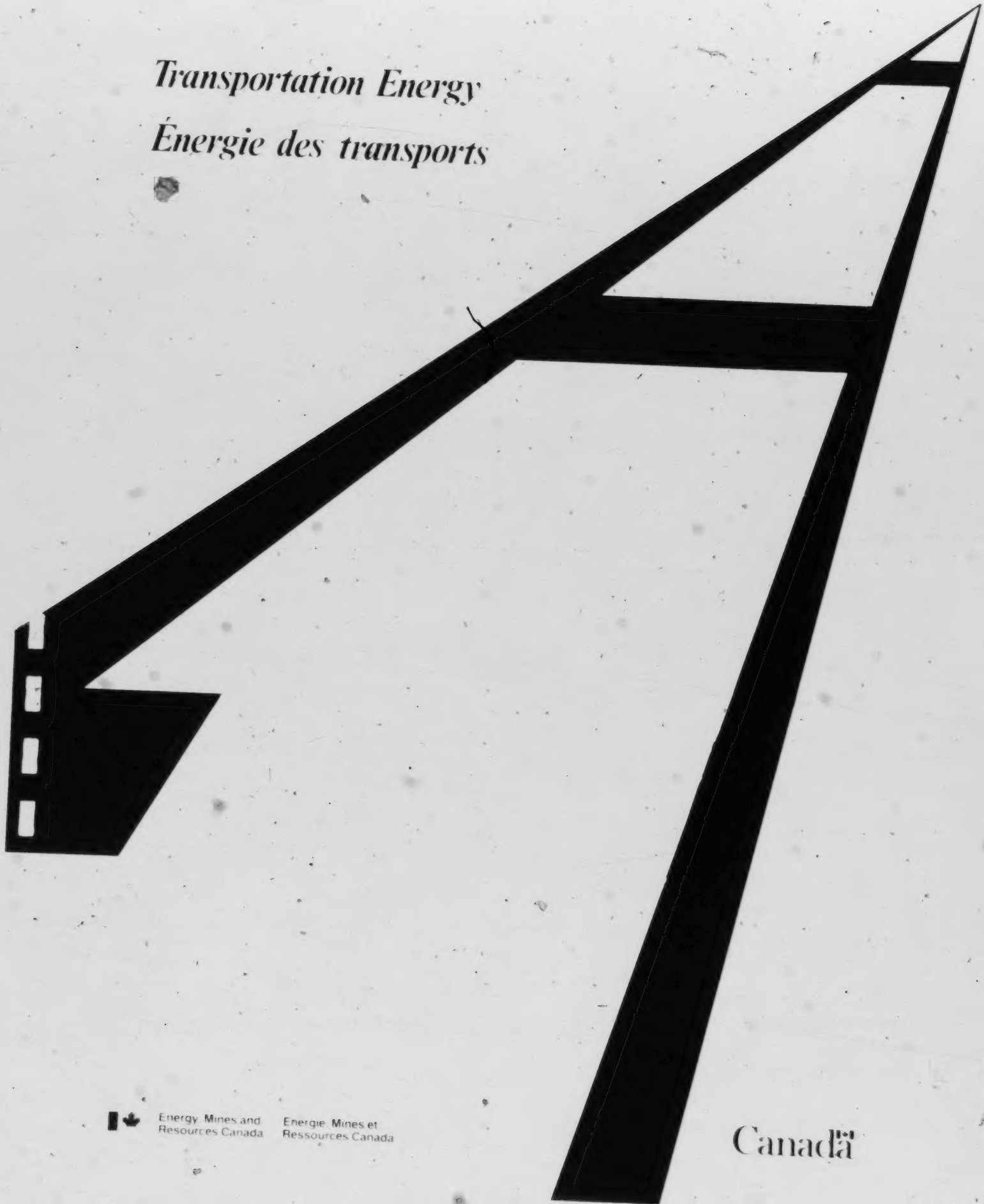

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AMBIENT TEMPERATURE EFFECTS ON CANADIAN GASOLINE DEMAND

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Energy, Mines and Resources

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AMBIENT TEMPERATURE EFFECTS ON CANADIAN GASOLINE DEMAND

SUMMARY

OBJECTIVE

The objective of this report is to estimate the effect on Canadian gasoline demand due to the increase in fuel consumption caused by cold ambient temperature conditions.

The report also defines the potential for a reduction of gasoline demand in Canada through recommended improvements in automobile cold start and run operation through engine management practices and possible reductions in lubricant losses in transmissions and bearings.

RATIONALE, METHODOLOGY AND FINDINGS

Cold temperatures reduce the fuel efficiency of passenger cars. The reduction is called fuel consumption degradation. Fuel consumption degradation decreases with increasing trip length. Fuel consumption degradation increases with decreasing ambient temperatures.

Based on assumptions and premises contained in the text, the total effect of cold weather fuel efficiency degradation is estimated to be 1.32% of the Canadian passenger car gasoline demand, or 290 million litres (1.82 million barrels/Year or 11,140 TJ/Year).

Improvements in cold temperature fuel efficiency have been achieved over the last 20 years without specific legislation, with the penetration of fuel injection and more effective electronic control systems. There is reason to believe that the cold weather fuel consumption degradation is likely to continue to decline in the future as more fuel efficient control technologies are applied in the new vehicle fleet.

Future work in the ambient temperature degradation field should investigate the influence of driver habits on fuel demand, such as the use of block heaters (possibly with a recommendation to ensure that each new car is equipped with a block heater), as well as determining the effect of an ambient temperature calibration for the electronic engine management systems which some new cars are equipped with.

CONCLUSION

Based upon the assumptions and methodology used the effect of cold temperatures on Canadian gasoline demand is 1.323% from the assumptions and methodology use, therefore the potential for improvement in this area is probably not found in one engine feature but a combination of advancing technologies.

Consideration should be given to strategies or actions for vehicle manufacturers to improve ambient start degradation performance. This could take the form of a requirement for timed block heaters on new vehicles.

Manufacturers should be encouraged to optimize the fuel consumption of their vehicles by engine calibration at low winter temperatures.

RECOMMENDATIONS

Further study of the ambient temperature effects should be directed towards block heater technologies, to determine if a significant reduction in demand can be achieved.

Manufacturers should consider and comment on the benefits of calibrating engine management systems for various ambient temperatures.

GLOSSARY OF TERMS AND SYMBOLS

The following terms and nomenclature are used in this Report.

Ambient effect [V]: the additional volume (V) of gasoline consumed due to the operation of a motor vehicle at a temperature other than the reference temperature of 25°C. It refers to the entire on-road fleet.

Ambient start: a motor vehicle started after at least a six (6) hour soak at the surrounding temperature without any form of thermal assistance such as a block heater, heated garage, etc.

Ambient start distribution [A(M,td)]: the number of ambient starts in Canada on a monthly (M), trip distance (td) basis.

Ambient temperature [T]: a function of the ambient temperature, month, and location (L). It gives the number of days (N) at a given average temperature in that month for that location.

Canadian Average Temperature Distribution [CAD(T,M)]: the particular temperature which gives the population weighted average exposures to a temperature (T) in the month (M).

Fuel Consumption Degradation [D(T)]: The effect of low ambient temperatures on vehicle fuel consumption is called fuel consumption degradation. It is the change in fuel consumption due to the vehicle being operated at some ambient temperature other than the reference temperature of 25°C. The amount of degradation is a function of the ambient temperature (T) and is expressed as a degradation ratio.

Degradation ratio: This is the fuel consumption at the ambient soak temperature divided by the fuel consumption at the reference temperature of 25°C. Degradation ratios are generally between .95 and 1.9 where the higher numbers indicate decreased fuel efficiency.

EPA Bags: Relate to samples of exhaust gas collected from a motor vehicle being subjected to an EPA test driving cycle on a chassis dynamometer. Analysis of the bags gives emissions components and fuel consumption. three bags of samples are collected. In performing the tests, a vehicle follows a specified speed-time curve. The area under the curve represents the distance travelled. For each bag this distance is between three and four miles.

AMBIENT TEMPERATURE EFFECTS ON CANADIAN GASOLINE DEMAND

1.0 INTRODUCTION

There has been a concern that significant reductions in gasoline demand could be made by legislating improvements in vehicle cold temperature fuel consumption degradation characteristics. This originates with preconceptions in the 1970's that the gasoline demand in Canada must be drastically affected by the cold Canadian winters. This report examines the effect of cold weather on Canadian gasoline demand, which is called the ambient effect, taking into account modern engine technology.

1.1 AMBIENT EFFECT

The ambient effect (V) is the additional volume of gasoline used by the on-road passenger car fleet due to the operation of vehicles at temperatures other than the reference temperature of 25°C. The ambient effect is a function of the temperature distibutions, the vehicle use patterns, and the fuel consumption degradations.

1.2 VEHICLES

Gasoline burning passenger car degradations alone are considered in this report. Data is not generally available for the effects of ambient temperatures on vehicles other than passenger cars. Approximately 73%[1] of all on-road vehicles in Canada are considered passenger cars, and passenger cars use about 67%[2] of the total Canadian gasoline demand.

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1. Statistics Canada catalogue 53-219
2. Fuel Demand Evaluation Model, TEB.

1.3 FACTORS FOR A CHANGED FUEL DEMAND

Weather is obviously the key component of the cold weather fuel consumption. In this report, only the temperature aspect of weather is considered. To assess the impact of ambient temperatures (T), statistical methods are used to quantify the ambient temperature distribution [N(T,M,L)]: to give the number of days at an average temperature (T) during a month (M) at a particular location (L). This is done to get regional temperature distributions for a variety of locations in Canada, as a first step to a demographic approach in this analysis.

Automobile population data are used with the above demographic input to generate a Canadian average temperature profile from the regional temperature distributions, referred to as "Weather".

To estimate the total ambient effect, vehicle use patterns are employed. Vehicle use distributions can then be applied to the temperature profile to find a number of vehicles operating at each ambient temperature.

Next, the effect of a given ambient temperature on the average Canadian car is examined. This effect is called the fuel consumption degradation [D(T)] and it can be influenced by the application of various technologies.

The calculation of the total cold ambient temperature effect on gasoline demand is done by bringing together the weather, vehicle use patterns, and degradation data.

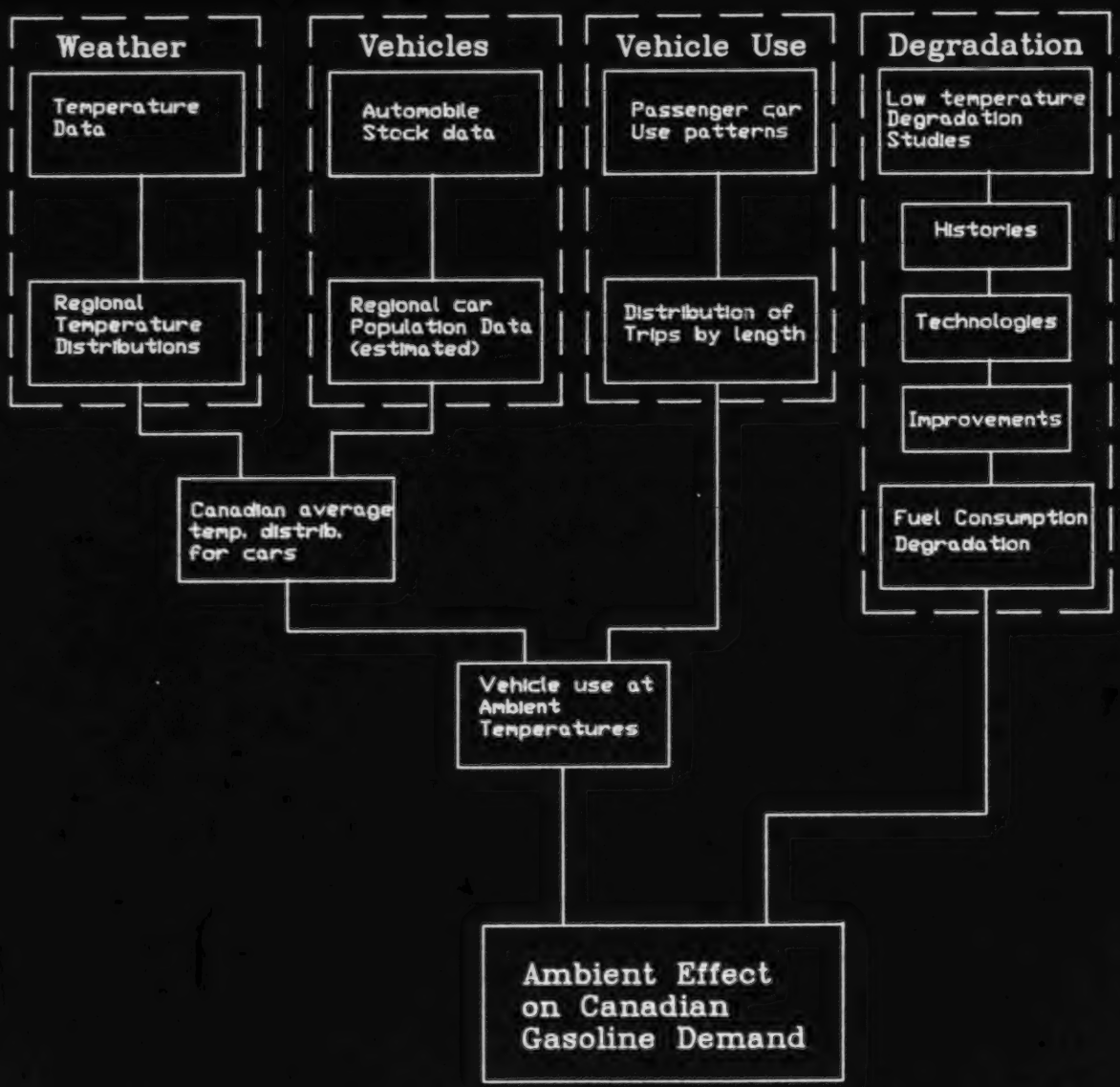
To find the potential for improvement, decreases in gasoline demand are calculated for several types of improved cold start technologies.

1.3.1 FACTORS NOT EVALUATED

Temperature effects alone are considered in the calculation of the ambient effect on gasoline demand. While other climatic conditions, as well as driver behaviour, have an effect on gasoline demand, these effects would be difficult to estimate accurately. For example, snow

tends to increase fuel consumption by allowing slippage between the tires and road. Snow tires tend to give higher rolling resistance. Increased air density at cold temperatures result in higher aerodynamic drag. The total effect of such factors is beyond the scope of this report.

Figure 1
Calculation Methodology



2.0 CALCULATION METHODOLOGY

A general plan for the calculations is used to find the ambient effect. To determine the effect of cold ambient temperatures on Canadian gasoline demand several steps are required to combine the elements involved. The various elements are described below and Figure 1 is a flow diagram of the required steps. In this diagram calculations proceed from top to bottom. This plan demonstrates how the weather, vehicle use patterns, and fuel consumption degradation data are combined to arrive at the total effect on Canadian gasoline demand. The methodology is explained below and the calculations are presented in the following chapters.

2.1 WEATHER CALCULATIONS

The weather calculations have four main components. These are:

1) the temperature data;
2) regional temperature distributions;
3) population data;
4) the Canadian average temperature distribution.

2.1.1 TEMPERATURE DATA

A consistent source of data for climatic conditions is required to quantify the regional temperature distributions can be generated from the temperature data using statistical methods. The temperature data is obtained from Environment Canada, Climatic Normals-Temperature.

2.1.2 REGIONAL TEMPERATURE DISTRIBUTIONS

Temperature distributions, which give the number of days at a given temperature are required for representative regions of Canada. These temperature distributions can be generated from the temperature data using statistical methods.

2.1.3 POPULATION DATA

Population data are required for Canada in order to select and properly weight the regional temperature distributions. These data, supplied by Statistics Canada, were used to obtain the Canadian average temperature distribution.

2.1.4 AUTOMOBILE POPULATION

Ideally, it would have been preferable to use automobile population data rather than the number of people but such data was not available on a regional basis. Therefore this report uses urban population from Statistics Canada, 1981 Census, as an estimator of vehicle population.

2.1.5 CANADIAN AVERAGE TEMPERATURE DISTRIBUTION

The Canadian average temperature distribution is derived from the regional distributions by population weighting each of the distributions and combining them. The Canadian average temperature distribution [CAD(T,M)] gives the number of days which have the average temperature T in the month M.

2.2 VEHICLE USE PATTERNS

Monthly vehicle use characteristics are employed, along with the Canadian average temperature distribution, to calculate the number of vehicles being used at each of the ambient temperatures considered in each month. The vehicle use charateristics are obtained from Transport Canada internal documents.

2.2.1 PASSENGER CAR USE

Passenger cars alone are considered for the calculations presented in this report, because data is not generally available for the fuel consumption degradation for other types of motor vehicles. Passenger cars consume the largest portion of the Canadian gasoline demand.

2.2.2 DISTRIBUTION OF TRIPS

The vehicle trip data is used in conjunction with the temperature distributions to arrive at the amount of fuel used at cold ambient temperature conditions where the degraded fuel consumption occurs.

2.3 FUEL CONSUMPTION DEGRADATION

To calculate the total ambient effect, the fuel consumption of the average Canadian car is needed for each ambient temperature. These fuel consumptions can be estimated from the results of available degradation studies.

2.3.1 DEGRADATION STUDIES

The average degradation ratios, and the average fuel consumption are computed from the degradation studies. These averages, which are computed using sales data, are used to represent the average degradations for the entire Canadian passenger car fleet.

From these results the amount of gasoline used because of the cold temperatures can be deduced for each car at each trip length. The volume of gasoline due to ambient start degradation is the difference between the volume used to travel the trip length under reference temperature conditions (25°C) and the volume used to travel the same trip length at a cold ambient temperature.

2.4 AMBIENT EFFECT

The total ambient effect on Canadian gasoline demand obtained by adding together the fuel used because of vehicle operation in cold soak conditions for the average Canadian passenger car at each temperature to obtain the average ambient effect per trip. This number is then multiplied by the number of trip in the on-road fleet to get the total ambient effect.

3.0 CALCULATION OF TEMPERATURE AND INCIDENCE

The temperature component of weather is the prime cause of degraded motor vehicle fuel consumption in the winter. While other climatic conditions might have an effect on gasoline demand, the effect of such conditions are not considered in this report.

3.1 TEMPERATURE DISTRIBUTIONS

Temperature distributions relate an ambient temperature to the number of days at that temperature. Regional temperature distributions are denoted N(T,M,L). They give the number of days at the ambient temperature T in the month M for the location L.

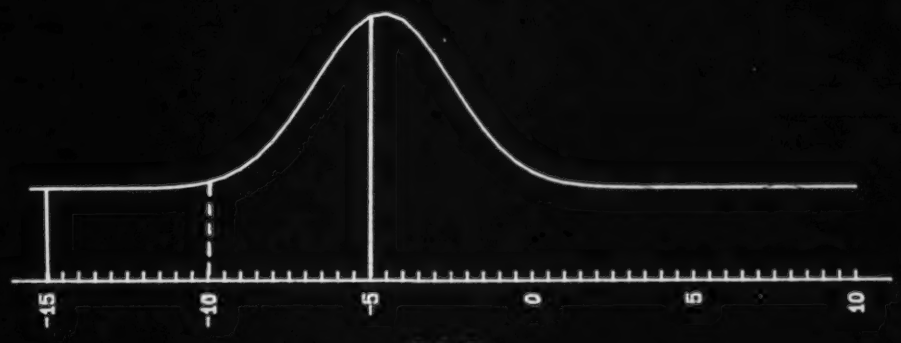
The calculate the effect of ambient temperatures on Canadian gasoline demand, the distribution of climatic temperature is needed for representative regions of Canada. It was decided to use a monthly basis and have a temperature distribution for each region for each month. These distributions are used to find the number of day at a given temperature in a given region for each month.

3.1.1 STATISTICAL METHODS

To quantify the temperature distribution for each region, we assume that the Normal Distribution approximates the actual range of temperatures. The Normal Distribution is typically used to model physical events which are continously distributed.

The Normal Distribution gives the probability density function (P.D.F.) for the range of temperatures. The P.D.F. is a function of two variables: the mean, which is a measure of central tendency, and the standard deviation, which is a measure of dispersion. The area under the P.D.F. between any two points on the X-axis represents the probability of that a value (temperature in this case) within that range will occur.

Figure 2
Normal Temperature Distribution
for Toronto in January



P.D.F.

for Toronto in January, $\mu = -4.6$ C (mean)
$\delta = 2.1$ C (standard deviation)

to find NK-10 C,January,Toronto), the ambient temperature distribution is used by applying the following fomulae:

$$NK\text{-}18C,Jan,Tor) = \int_{-15}^{-5} (\text{normal distribution}) * \#\text{of days in January}$$

$$= \int_{-15}^{-5} \frac{e^{(\mu-x)^2}}{\sqrt{2\pi}\,\delta}\,dx * 31 \qquad = \int_{-15}^{-5} \frac{e^{(-4.6-x)^2}}{\sqrt{2\pi}\,2.1}\,dx * 31$$

the Simpson's Rule approximation is then used to evaluate the integral

$$= \frac{(b-a)}{3n}\,(\,f(x1) + 4f(x2) + \ldots + 4f(xn-1) + f(xn))$$

$$= \frac{(-5-15)}{18}\,(0.000 + 0.080 + 0.001 + 0.029 + 0.078 + 0.467 + 0.185\,) * 31$$

$\therefore$ NK-18C, Jan, Tor) $= 0.423 * 31 = 13.1$ days

To generate the number of days at a given temperature in a given month from a P.D.F., two steps are required. First, we must find areas. This is done by integrating, in the mathematical sense, the probability density function of the normal temperature distribution. This integration is performed over some range (see Figure 2). The resulting probabilities are then multiplied by the number of days in the corresponding months to get the number of days in the month at a given temperature.

Simpson's Rule is used to evaluate the definite integrals formed above because the Normal Distribution has no anti-derivative and can only be integrated by numeric means.

Simpson's Rule uses a quadratic approximation to find the area under a curve. Simpson's Rule states:

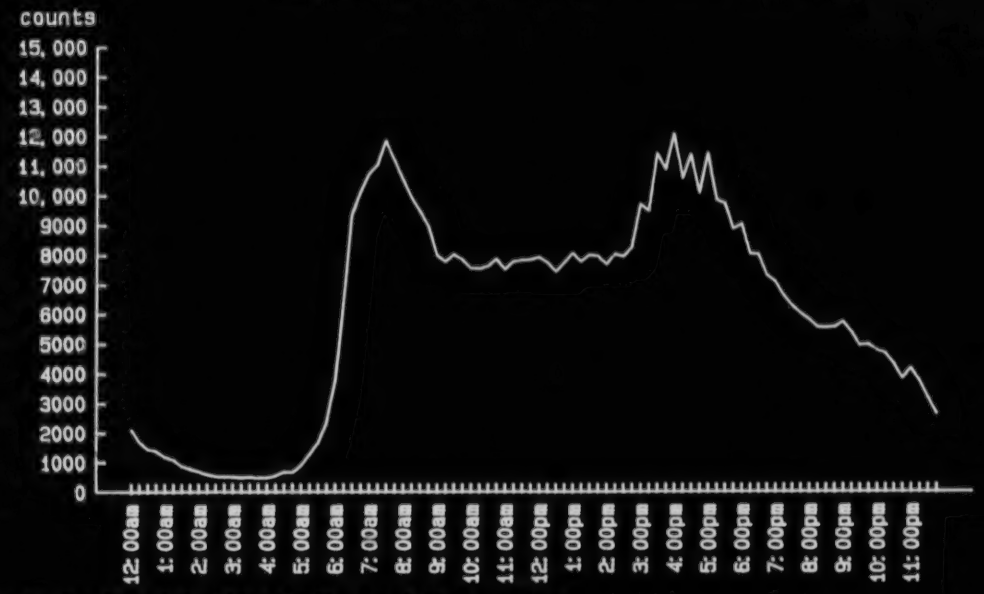
$$\int_b^a f(x)dx \approx \frac{(b-a)}{3N}\,(f(x1)+4f(x2)+\ldots+4f(xn-1)+f(xn))$$

where N = the number of subdivisions
(chosen to be even)

For all applications of Simpson's Rule in this report, six subdivisions were used.

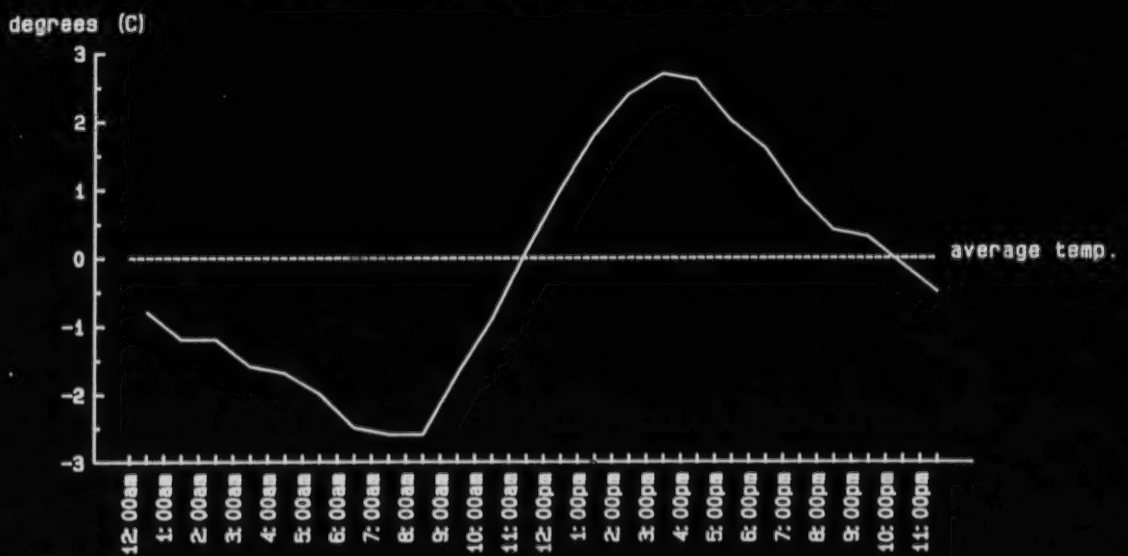
The degradation data indicated that temperatures of +20°C, +10°C, 0°C, -10°C, and -20°C would be the suitable points around which to integrate. A range (b-a) of 10°C was chosen for each integration. Since the ranges are continuous and do not overlap, combining the number of days at each temperature for each month generates a profile of days versus temperature. This profile is a graphical representation of the temperature distribution for the year.

Figure 3a
Typical Distribution of Vehicle Usage



Source: Regional Municipality of Ottawa-Carleton
Transportation Division

Figure 3b
Typical Distribution of Temperature
Relative to Average Daily Temperature



Source: Environment Canada
Monthly Meteorological Summary

3.2 TEMPERATURE NORMALS

The temperature distributions are a function of both the mean and standard deviation of the temperature. These two variables are needed to form the P.D.F.s used in this report. Environment Canada publishes Climatic Normals = Temperature (UDC: 551.582 (71)) which includes the temperature means and standard deviations for all major Canadian population centres on a monthly basis. These numbers are calculated from average daily temperatures over the period 1951-1980. Environment Canada defines the daily mean temperature as the mid point of the daily high and low temperatures. Monthly means and standard deviations are calculated from these data. These results allow the regional temperature distributions to be computed for each population centre in Canada.

Not all trips in any given day occur when the temperature is at its daily mean. To determine the effect of using the approximation that all trips occur at the daily mean temperature, data for the typical distribution of trips within a day, and for the typical distribution of temperatures within a day are required.

The distribution of trips within any day was not available from the Transport Canada trip survey. The best available data was found in the traffic counts conducted by the Regional Municipality of Ottawa-Carleton. These traffic surveys give the number of motor vehicles passing through a given intersection in 15 minute intervals for a 24 hour period. Twenty one intersections were chosen to be typical, and the resulting data represent 551,000 vehicle counts. The resulting graph (Figure 3a) was considered by the traffic analysts at the Transportation Department of the Regional Municipality to be representative of traffic patterns in most populated locations.

The distribution of temperatures within a day were computed using data contained in Environment Canada's Monthly, Meteorological Summaries for St. John's, Ottawa, Toronto, Calgary, and Vancouver. The summaries

Table 1

Population of Canadian Cities Chosen for this Evaluation

	PROV.	POP.	% OF CANADA	% OF DATA
TORONTO	Ont.	2,998,947	12.3%	22.3%
MONTREAL	Que.	2,828,349	11.6%	21.1%
VANCOUVER	B.C.	1,268,183	5.2%	9.4%
OTTAWA-HULL	Ont.	717,987	2.9%	5.3%
EDMONTON	Alta.	657,057	2.7%	4.9%
CALGARY	Alta.	592,743	2.4%	4.4%
WINNIPEG	Man.	584,842	2.4%	4.4%
QUEBEC CITY	Que.	576,075	2.4%	4.3%
HAMILTON	Ont.	542,095	2.2%	4.0%
ST. CATHERINES	Ont.	304,353	1.3%	2.3%
KITCHENER	Ont.	287,801	1.2%	2.1%
LONDON	Ont.	283,668	1.2%	2.1%
HALIFAX	N.S.	277,727	1.1%	2.1%
WINDSOR	Ont.	246,110	1.0%	1.8%
VICTORIA	B.C.	233,481	1.0%	1.7%
REGINA	Sask.	164,313	0.7%	1.2%
ST. JOHN'S	Nfld.	154,820	0.6%	1.2%
OSHAWA	Ont.	154,217	0.6%	1.1%
SASKATOON	Sask.	154,210	0.6%	1.1%
SUDBURY	Ont.	149,923	0.6%	1.1%
CHICOUTMI	Ont.	135,172	0.6%	1.0%
THUNDER BAY	Ont.	121,379	0.5%	0.9%
TOTAL		13,433,452	55.18%	100.00%
CANADA		24,343,180	100.00%	181.21%

Comment: By using the above 22 cities, calculations account for 55% of Canadian population

Source: Statistics Canada

contain hourly temperature data for each day for each of these locations. Sample days were selected from the data. One day was selected from each winter month (Nov., Dec., Jan., Feb., Mar.) from each location. The day chosen was generally the first day of each month unless that day ended at a temperature more than 3 degrees different from the starting temperature. This was done so that the effect of passing weather systems would not tend to "flatten" the daily temperature distribution curve. A typical distribution of daily temperature was computed from these data (see Figure 3b).

By correlating the temperature distribution to the vehicle usage distribution, it was estimated that 55% of trips occur when the temperature is above the daily mean, while 45% occur while the temperature is below the daily average. Since the daily variation in temperature was only $\pm 3°C$, the assumption that the average trip occurs at the mean temperature was deemed adequate for this report. The effect of this assumption is to slightly over estimate the total ambient effect.

3.3 REGIONS

Cities were chosen to represent regions in Canada. This made it possible to use the weather data, which are available on a city to city basis.

The twenty two most populous urban centres in Canada were chosen from the Statistics Canada 1981 Census (tabulated in Census metropolitan areas and census agglomerations with components; cataloue 95-903, ISBN 0-660-51161-4). The 22 cities account for a total of 58.2% of all Canadians. The urban centres are identified by the largest city they contain.

The twenty two cities chosen represent 79.9% of the urban population in Canada (see Table 1). If 44 cities had been chosen they would have increased the data-base to cover 90% of the population data, a gain of just 10%. The 22 cities give sufficient accuracy with the least amount of calculation. Table 2 gives the weather data for the selected cities.

Table 2

Canadian Temperature Data for Selected Cities

	january		february		march		april		may		june	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
TORONTO	-4.6	2.1	-3.9	2.3	0.7	1.8	7.6	1.5	13.6	1.8	19.1	1.2
MONTREAL	-10.2	2.5	-9	2.2	-2.5	2.2	5.7	1.3	13	2.1	18.3	1.2
VANCOUVER	2.5	1.9	4.6	1.4	5.8	1.1	8.8	0.9	12.2	1	15.1	1.2
OTTAWA-HULL	-10.9	2.5	-9.5	2.5	-.3	2.2	5.6	1.5	12.8	2	18	1.2
EDMONTON	-15	4.6	-9.6	4.3	-.5	3.3	4.2	2.3	11.3	1.4	15.1	1.3
CALGARY	-11.8	4.8	-7.3	4.3	-.4	3.2	3.3	2.6	9.4	1.5	13.5	1.5
WINNIPEG	-19.3	3.1	-15.6	2.9	-8.2	3.9	3.4	2.7	11.3	3	16.8	1.5
QUEBEC CITY	-12.1	2.3	-10.8	2.8	-4.5	2.1	3.3	0.7	10.8	1.4	16.4	1.4
HAMILTON	-4.6	2.4	-3.9	2.2	0.7	1.9	7.6	1.4	13.6	2.1	19.1	1.3
ST. CATHARINES	-4.7	2.1	-4.2	2.4	0.2	1.7	6.5	1.4	12.6	1.6	18.5	1.2
KITCHENER	-6.9	2.3	-5.8	2	-1.3	2.1	6.4	1.8	12.6	2	18.1	1.3
LONDON	-6.6	2.4	-6.1	2.6	-0.9	2.2	6.4	1.7	12.4	1.9	17.9	1.3
HALIFAX	-4.1	2.2	-4.5	1.9	-0.8	1.2	4	1.2	8.9	1	13.9	0.7
WINDSOR	-4.9	2.5	-3.8	2.3	1.2	2	8.1	1.5	14.2	1.8	19.7	1.3
VICTORIA	4.1	1.6	5.8	1.3	6.7	1.1	9.1	0.8	11.9	1	13.8	0.9
REGINA	-17.9	4.1	-13.6	3.8	-7.8	4.2	3.3	2.9	11.1	1.8	15.9	1.6
ST. JOHN'S	-5.8	2	-4.3	3.1	-2	2.2	1.6	1.3	5.8	1.5	11.1	2
[illegible]	-5.6	2.6	-4.9	2.4	-0.2	2.2	6.4	1.3	11.9	1.6	17.4	1.3
SASKATOON	-19.3	4	-14.6	3.8	-8.6	3.9	3.3	2.9	11.1	1.3	15.7	1.8
SUDBURY	-13.7	2.4	-12.5	2.6	-6	2.3	2.7	1.4	10.5	2	16	1.2
CHICOUTIMI	-14.7	3	-12.8	3	-5.3	2.6	3.1	1.3	10.1	1.8	14.4	1.3
THUNDER BAY	-15.3	2.8	-13	2.9	-6.3	2.5	2.5	1.4	8.8	1.7	14	1.1

	july		august		september		october		november		december	
	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
TORONTO	22	1	21.2	1.3	17.1	1.3	11	1.6	4.9	1.5	-1.8	2
MONTREAL	20.9	1.2	19.6	1.3	14.8	1.5	8.7	1.7	2	1.7	-4.9	2.7
VANCOUVER	17.3	1.1	17.1	1	14.2	1	10	0.8	5.9	1.2	3.9	1.6
OTTAWA-HULL	20.6	1.2	19.2	1.3	14.3	1.4	8.1	1.6	1.2	1.7	-7.7	2.8
EDMONTON	17.4	1.1	16.2	1.8	11	2.2	5.8	1.8	-3.7	4	-10.4	4.5
CALGARY	16.4	1	15.2	1.7	10.6	2.2	5.5	2.3	-2.7	3.8	-7.8	4.4
WINNIPEG	19.6	1.6	18.3	1.7	12.4	2	6.1	1.6	-4.5	2.1	-14	3.3
QUEBEC CITY	19.1	1.3	17.5	1.4	12.6	1.5	6.6	1.3	-0.2	1.6	-7	2.6
HAMILTON	22	0.7	21.2	1.1	17.1	1.1	11	1.7	4.9	1.6	-1.6	1.8
ST. CATHARINES	21.2	1.4	20.6	1.3	16.6	1.5	10.1	1.2	4.3	1.6	-1.5	2.5
KITCHENER	20.6	1.3	19.7	1.3	15.6	1.4	9.5	1.9	2.9	1.8	-3.9	2.1
LONDON	20.3	1.2	19.5	1.3	15.4	1.4	9.4	1.8	3.1	1.7	-3.5	2.2
HALIFAX	17.4	1.1	17.8	0.9	14.5	1	9.5	0.9	4.6	1.2	-1.5	2.4
WINDSOR	22.2	1.1	21.3	1.2	17.4	1.3	11.1	1.8	4.4	1.6	-1.9	2.2
VICTORIA	15.4	0.8	15.3	0.7	14.2	1	10.8	0.7	7.2	1.1	5.3	1.4
REGINA	18.9	1.3	17.8	1.8	11.7	1.9	5.2	1.6	-5.1	3.2	-12.8	3.9
ST. JOHN'S	15.6	1.8	15.5	1.5	11.6	0.7	7.1	1	3.5	1.6	-1.4	2.4
[illegible]	20.3	0.7	19.8	1.2	15.9	0.9	9.8	1.9	4.1	1.3	-2.6	2.2
SASKATOON	18.5	1.2	17.2	1.5	11.2	1.6	4.9	2.5	-5.7	3.6	-14.1	4.7
SUDBURY	18.7	1.1	17.3	1.6	12.2	1.4	6.3	2.1	-1.2	2	-10.2	2.6
CHICOUTIMI	19.1	1.4	17.4	1.2	12.3	1.4	6.5	1.5	-4.7	1.8	-10.6	2.7
THUNDER BAY	17.6	1.1	16.4	1.4	11.1	1.3	5.7	1.8	-2.6	2	-11.1	3

Source: Environment Canada - A.E.S.

Automobile distributions are not used to weight the temperature distributions since no source of data could be found that would give the vehicle population on a city by city basis which would coincide with the temperature data. Data for automobile stock is available on a provincial basis and is, given as Figure 4a, which shows that the ratio of automobiles to people is relatively constant throughout Canada. In addition, Figure 4b shows that the regions which tend to have fewer cars per person also tended not to have as many population centers included in this study. Therefore, it is felt that the population weighted temperature profile is suitable for the purposes of this report.

3.4 CALCULATING THE REGIONAL TEMPERATURE DISTRIBUTIONS

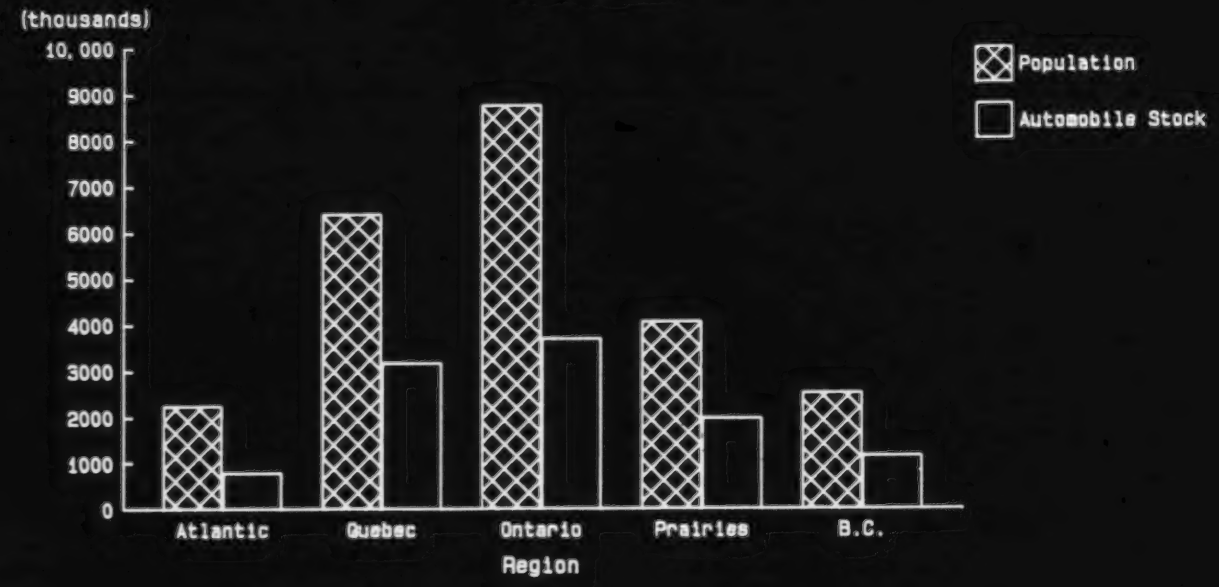
Th city population data are merged with the corresponding monthly temperature means and standard deviations using a spreadsheet program (Lotus 123) on a personal computer (Compaq+).

The Simpson's Rule approximation is then applied to find the probabilities of a given temperature occurring in a city in a given month. Multiplying the temperature probabilities by the number of days in the corresponding month gives the expected number of days that will have the chosen average temperature in that month. This results in a temperature distribution for each city for each month.

A sample calculation is included with Figure 2. The result of that calculation is the number of days between -15°C and -5°C in Toronto in January.

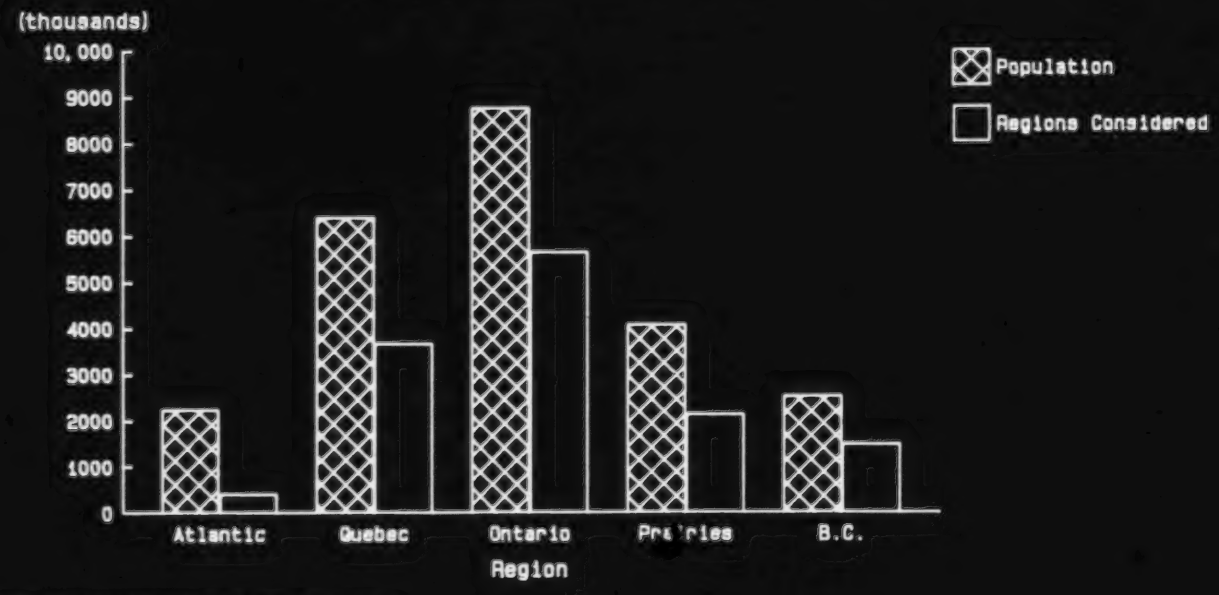
The distributions resulting from the calculation for the 22 cities for the 12 months at the 6 temperatures (=22*12*6=1584 individual P.D.F.s) are included as Appendix 1. The temperatures for the remainder of this report are given as the centre point, with the plus or minus 5°C implied.

Figure 4a
Automobile Stock and Population by Region



Source: Transportation Energy Data Book

Figure 4b
Regions Considered vrs Population



Source: Transportation Energy Data Book

3.5 CANADIAN AVERAGE TEMPERATURE DISTRIBUTION

The Canadian average temperature distribution gives the number of days that the average Canadian spends in a month at a particular temperature.

The population weighted average days at a given temperature is computed by:

$$CAD(T,M) = \sum (F(L) * N(T,M,L))$$

where $F(L)$ = the fraction of the Cdn. population in the location L

and $N(T,M,L)$ = the regional monthly temperature distribution

The resulting Canadian average days at a given mean temperature are given as Table 3 with the results presented graphically as Figure 5.

The results indicate that the incidence of cold temperatures in Canada are generally much smaller than is generally believed. Only 6.4 days per year have a mean of -20°C or under, suggesting that perhaps cold weather degradation studies might be more useful if they were to concentrate on the -10°C to +10°C range of temperatures where the average Canadian spends over 250 days during the year.

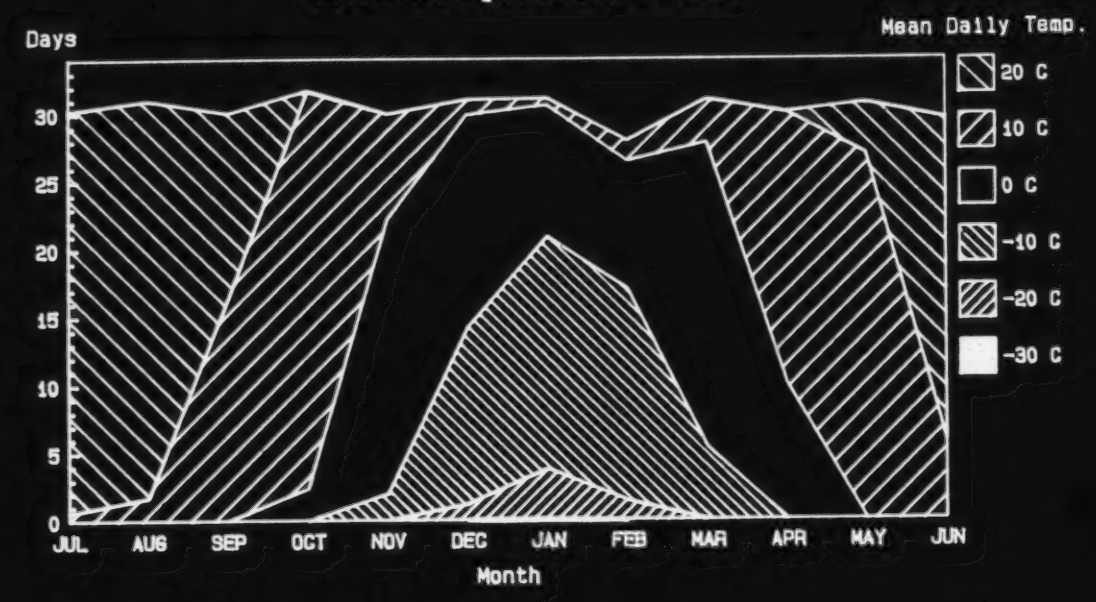
Table 3

Canadian Average Days with a Mean Temperature

	-30 C	-20 C	-10 C	0 C	+10 C	+20 C
January	0.1	3.7	17.1	9.7	0.5	-
February	-	1.4	15.6	9.4	1.5	-
March	-	-	5.3	22.5	3.2	-
April	-	-	-	10	20	-
May	-	-	-	-	26.9	3.8
June	-	-	-	-	5.8	23.7
July	-	-	-	-	0.6	29.6
August	-	-	-	-	1.7	29.3
September	-	-	-	-	16.3	13.7
October	-	-	-	2.4	29.2	0.1
November	-	-	2	20.2	7.7	-
December	-	1.2	13	15.7	1.1	-
TOTAL	0.1	6.3	53	89.9	114.5	100.2

Note: temperatures plus or minus 5 C

Figure 5
Population Weighted
Mean Temperature Profile



Source: Environment Canada

Table 4

Transport Canada Trip Data

	miles 0-4	5-8	9-12	>12	total trips
January	60.66%	18.38%	7.27%	13.69%	572,770,000
February	58.44%	16.79%	8.92%	15.85%	503,840,000
March	61.62%	16.49%	8.57%	13.32%	672,210,000
April	57.50%	18.51%	8.56%	15.43%	596,890,000
May	54.10%	19.33%	10.35%	16.22%	702,760,000
June	55.69%	18.76%	8.64%	16.91%	683,350,000
July	51.88%	20.65%	9.68%	17.79%	673,850,000
August	52.37%	19.41%	8.67%	19.55%	665,750,000
September	56.80%	17.58%	8.51%	17.11%	663,790,000
October	56.58%	19.56%	8.94%	14.92%	691,750,000
November	56.08%	19.85%	8.69%	15.38%	603,660,000
December	57.72%	17.62%	8.48%	16.18%	522,150,000

4.0 VEHICLE USE PATTERNS

Passenger car use varies by hour by day and by month. For calculating the exposure of vehicles to ambient temperature conditions, monthly variations are needed to correlate with the Canadian Average Temperature Distribution.

The monthly variation in vehicle use must be accounted for because gasoline demand in Canada decreases in the winter months. This occurs even though vehicle fuel consumption increases due to the lowered ambient temperatures. Therefore, if constant vehicle use was assumed, one would have to conclude that vehicle fuel consumptions actually decrease during the winter months.

To calculate the effect of cold weather on gasoline demand, the ambient start distribution [A(M,td); M = month, td = trip distance] is used. This distribution gives the number of ambient starts as a function of the month and trip distance. When the distribution of ambient starts is known, the number of ambient starts at each ambient temperature range can be computed by introducing the Canadian average temperature distribution.

4.1 TRIP DATA

Data for the number of ambient starts are not directly available but Transport Canada has collected data from 153,000 trip records. The number of vehicle starts is deduced from these data.

The trip data from Transport Canada is in the form of estimated trip frequencies by month on a Canada wide basis. In their survey, Transport Canada defined a trip as having a single destination. They required that returning be a separate trip. A trip terefore essentially corresponds to a single ignition-on, ignition-off cycle. Transport Canada estimates that a minimum of 96% of the collected trip records are represented by this cycle. The data are presented as Table 4.

Figure 6a
Estimated Ambient Start Percentage

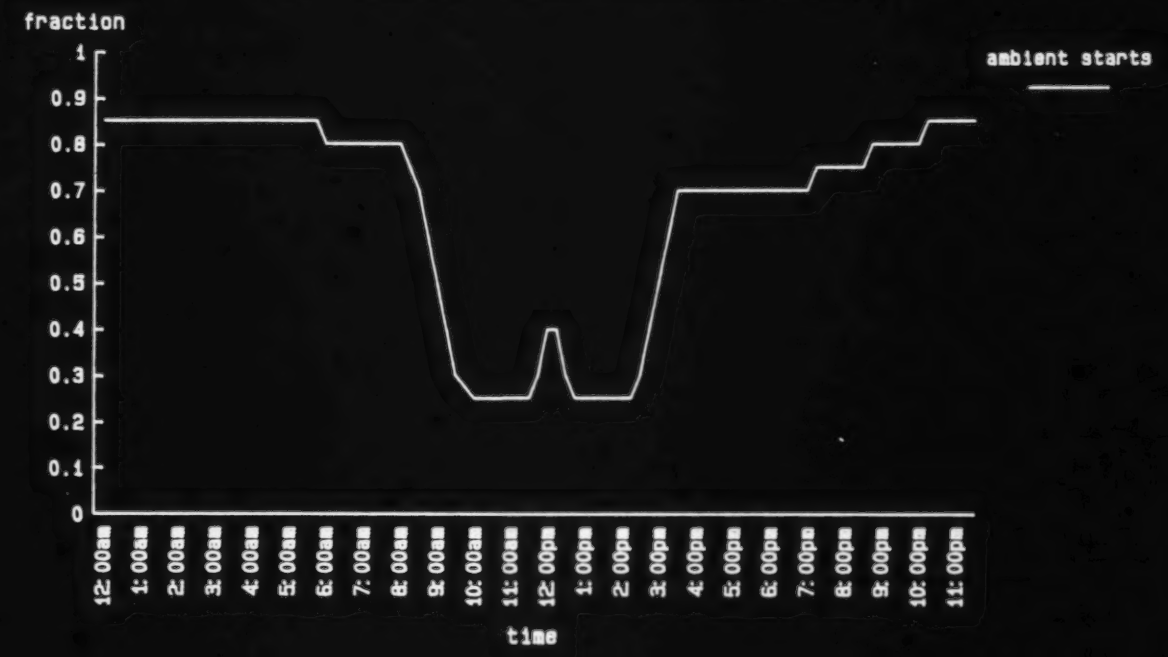
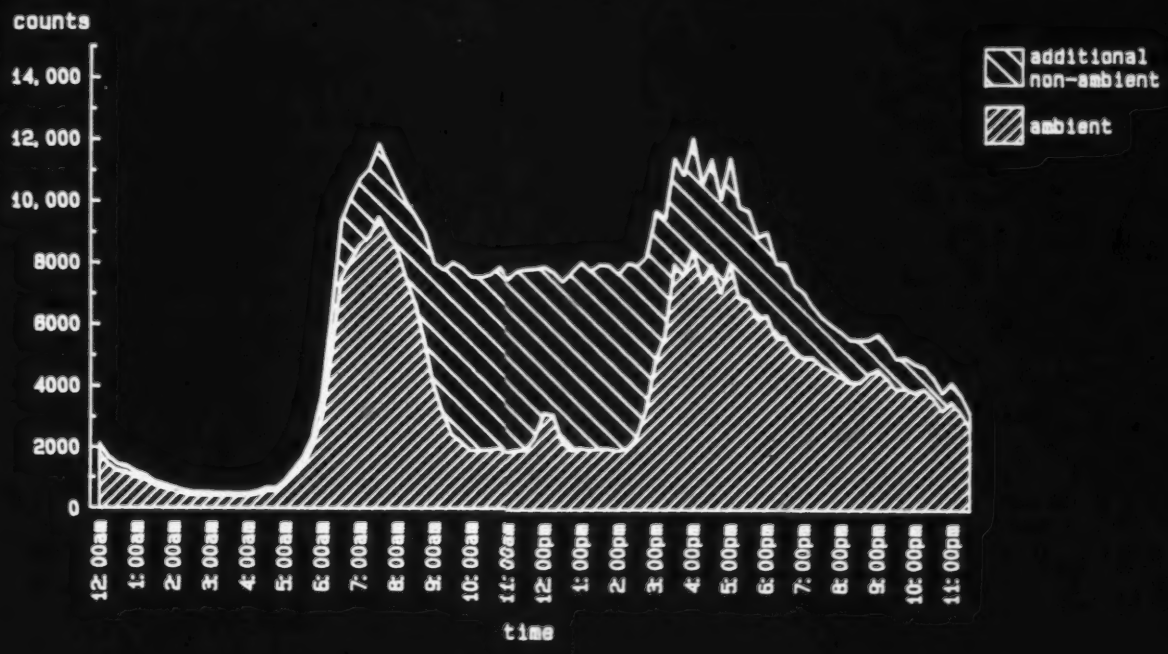


Figure 6b
Estimated Ambient Start Distribution



From EMR/TEB, an estimate of the number of passenger cars on the road in 1981 is 10,255,551. The trip data therefore suggests an average of 2.02 trips per car per day.

4.2 AMBIENT START PERCENTAGE

To determine the ambient effect on gasoline demand, a figure for the percentage of trips which begin with an ambient start must be derived. Because data are not available for this area, this report uses the traffic count data, as well as some arbitrary but reasonable assumptions about ambient starts to arrive at the ambient start percentage. It was assumed that most trips between 3:30 pm and 8:30 am were ambient starts. Trips between 9:30 and 3:00 were assumed to represent primarily vehicles in use throughout the day and were therefore not ambient starts. A rise in the ambient start percentage was allowed for at noon to represent the vehicles which are used only once during the day (i.e. shopping, etc.). The actual fractions of trips considered to be ambient starts are given as Figure 6A.

When these fractions are applied to the traffic count data it was found that 60% of all trips would be ambient starts. (See figure 6b).

This figure of 60% of starts are ambient starts will be used in the remainder of this report to estimate the ambient effect on Canadian gasoline demand.

5.0 FUEL CONSUMPTION DEGRADATION

It is common knowledge that vehicle fuel consumption is degraded in cold weather. There are several factors which affect the amount of degradation. Snow and snow tires cause increased rolling resistance. Lubricant viscosity is raised, resulting in higher friction in the engine and drive-line. Engine efficiency is impaired due to the inability of the induction system to properly vaporize the gasoline at low intake air temperatures. Also, increased air density results in additional aerodynamic losses. Only engine efficiency and drive-line effects are considered for calculation in this report.

The effect of ambient temperatures on vehicle fuel consumption is called fuel consumption degradation [D(T)]. It is expressed as a degradation ratio, which is the fuel consumption at the ambient temperature divided by the fuel consumption at the reference temperature of 25°C. Degradation ratios are generally between .95 and 1.90, where higher numbers indicate decreased fuel efficiency.

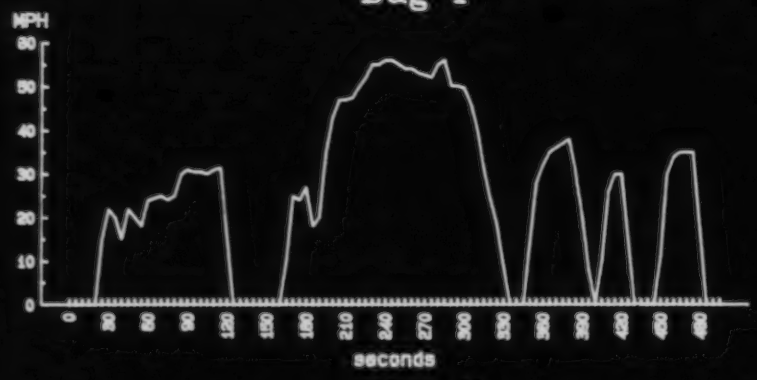
A source for representative degradation ratios for the Canadian on-road passenger car fleet at all relevant temperatures was required.

5.1 DEGRADATION STUDIES

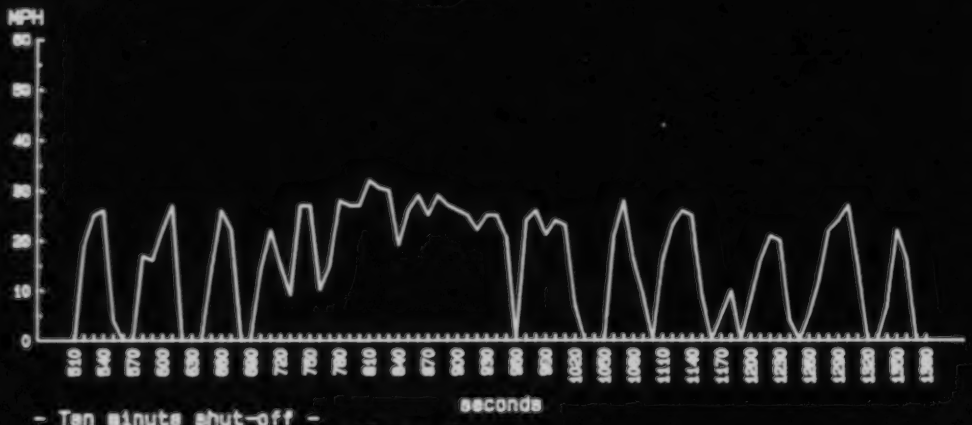
Cold temperature testing has been done by both passenger car manufacturers and independent testing agencies. Often, however, this testing is done at temperatures which occur infrequently (e.g. = -40°C). While the manufacturer wishes to ensure that his car will start at extremely cold temperatures, fuel consumption data from such tests have little applicability for determining effect on gasoline demand. Studies which cover the significant range of temperatures (-20°C to 20°C) are required.

Experiments designed to measure the degradation of fuel efficiency usually give the results from the Environmental Protection Cycle. The cycle results from the Environmental Protection Agency's exhaust emission testing. In performing these tests, a vehicle follows a specific

Figure 7
EPA City Cycle
Bag 1

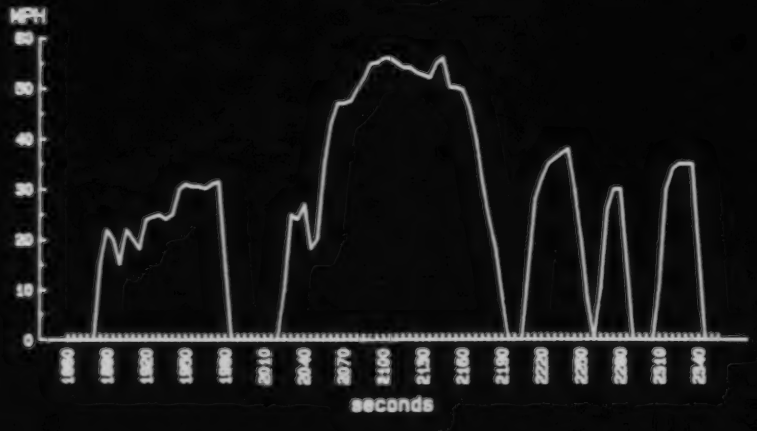


Bag 2



- Ten minute shut-off -

Bag 3



speed-time curve (see Figure 7). A sample of exhaust gas is taken for each of the three bags, and the fuel consumption can be determined by a chemical analysis of the gases in the sample bags.

The distances travelled by the vehicle during a city cycle are between three and four miles. In order to coincide with the trip data, the distance travelled for bag one is assumed to be 4.99 miles, with 4.00 miles assumed for bags two and three.

In order to determine the effect of ambient temperatures on Canadian gasoline demand, it was necessary to use two degradation studies for this report.

5.1.1 GIMVEC/GM STUDY

One study, a summary of data collected by the US EPA, was presented by General Motors of Canada to the GIMVEC Cold Weather Subcommittee. This study, which involved 98 cars, will be referred to as GIMVEC/GM. It gives fuel consumption degradations for a twelve hour ambient temperature soak at 10°C and -6.7°C compared to the reference temperature of 25°C. The cars represented are all gasoline engined, 1981 to 1983 model year, passenger cars produced by various foreign and domestic manufacturers. The cars have odometer readings from 294 to 97251 miles. The GIMVEC/GM data list the fuel degradation ratio and the actual fuel consumption by bag and temperature for each of the 98 cars.

The GIMVEC/GM data are used to estimate the average fuel efficiency degradation of the 10,250,000 vehicles in the on-road passenger car fleet. In order to calculate the average ambient fuel degradation for the typical Canadian car, the fuel degradations are sales weighted. Sales figures for each model in the study are combined with the data. The vehicles in the study represent a total of 349,782 on-road cars. (Sales figures are not included in this report, however, as they are supplied in confidence to the Government of Canada by the vehicle manufacturers).

The degradations for the two test temperatures are assigned two the temperature range in which they occur. Thus, the +10°C data were

Table 5
GIMVEC\GM Average Degradations

temperature	EPA bag	fuel consumption	degredation ratio
+20 C	1	11.44	1.00
	2	10.94	1.00
	3	9.52	1.00
+10 C	1	13.37	1.17
	2	11.52	1.05
	3	9.99	1.05
-10 C	1	15.40	1.35
	2	11.74	1.07
	3	10.25	1.08

Table 6
LTEP Average Degradations

temperature	EPA bag	fuel consumption	degredation ratio
+20 C	1	14.43	1.00
	2	12.45	1.00
	3	11.67	1.00
+10 C	1	15.53	1.06
	2	12.99	1.04
	3	12.01	1.03
0 C	1	16.58	1.15
	2	13.56	1.09
	3	12.40	1.06
-10 C	1	18.27	1.27
	2	14.17	1.14
	3	12.75	1.09
-20 C	1	20.67	1.43
	2	14.83	1.19
	3	13.17	1.13

assigned to the +10°C range, and the -6.67°C data were assigned to the -10°C range. See Table 5 (and Figure 8a) for the resulting degradation ratios.

Because the GIMVEC/GM study provides degradation data for only two of the required four significant ambient temperatures, more data were necessary to determine the full range of ambient degradations.

5.1.2 LOW TEMPERATURE EFFECTS PROGRAM STUDY

A low temperature fuel efficiency degradation study was performed by Dr. Nicholas Ostrouchov of the Low Temperature Effects Program administered by Transportation Systems Division, Environment Canada. His study (referred to as LTEP) involved 39 cars ranging in model years from 1963 to 1981. Fourteen of these cars are recent model years, (1978 to 1981), and the remainder are older than 1976. For calculation of the ambient effect, only 1978 to 1981 model year vehicle data were used. The data presented by that study were on an EPA City Cycle basis for six ambient soak temperatures (-20°C, -10°C, 0°C, 10°C, 20°C, 30°C). Table 6 lists the LTEP data and figure 4b presents this information as a graph.

To ensure consistency of the degraded fuel consumption numbers from one study to the other, the LTEP degradations were factored to coincide with the GIMVEC/GM degradations. The GIMVEC/GM data were considered more reliable since they represent many more vehicles. The factoring was done by calculating the adjustment necessary to make the +10°C and 10°C degradations identical. Each adjustment is then applied to the next lower temperature of the LTEP study.

5.2 DEGRADATION VERSUS TECHNOLOGY

The GIMVEC/GM data were broken down by various technologies to inspect the effect of various technologies already in place on fuel consumption degradations. From Table 7a to 7c one can see that no particular technology has any great advantage in the ambient degradation area. Fuel injection offers an advantage over carburettors, and this will be discussed in the chapter on future improvements (7.0 POTENTIAL

Figure 8a
Fuel Efficiency Degradation
(GIMVEC/GM)

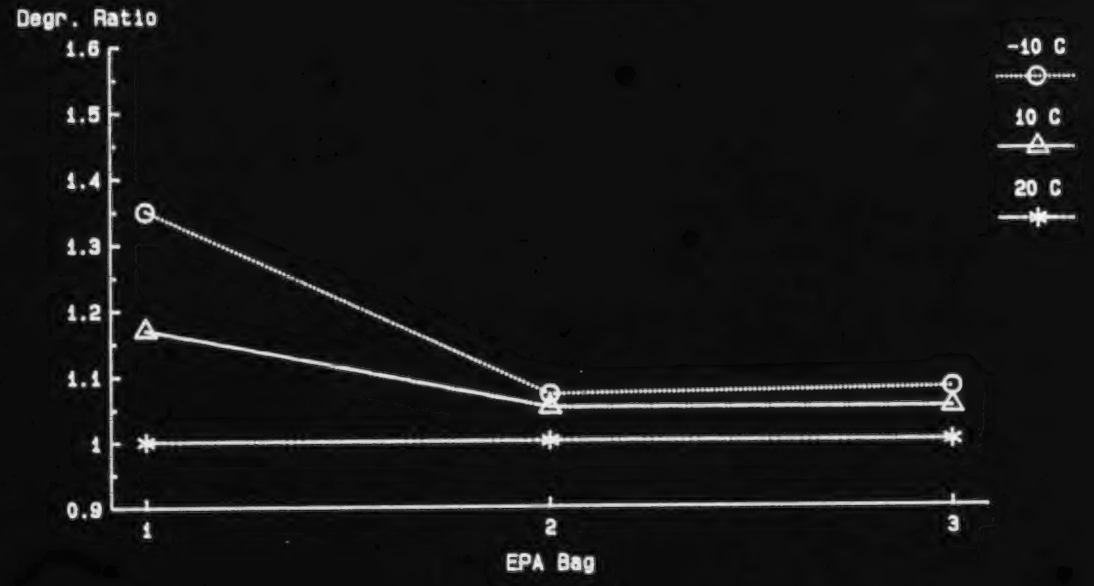
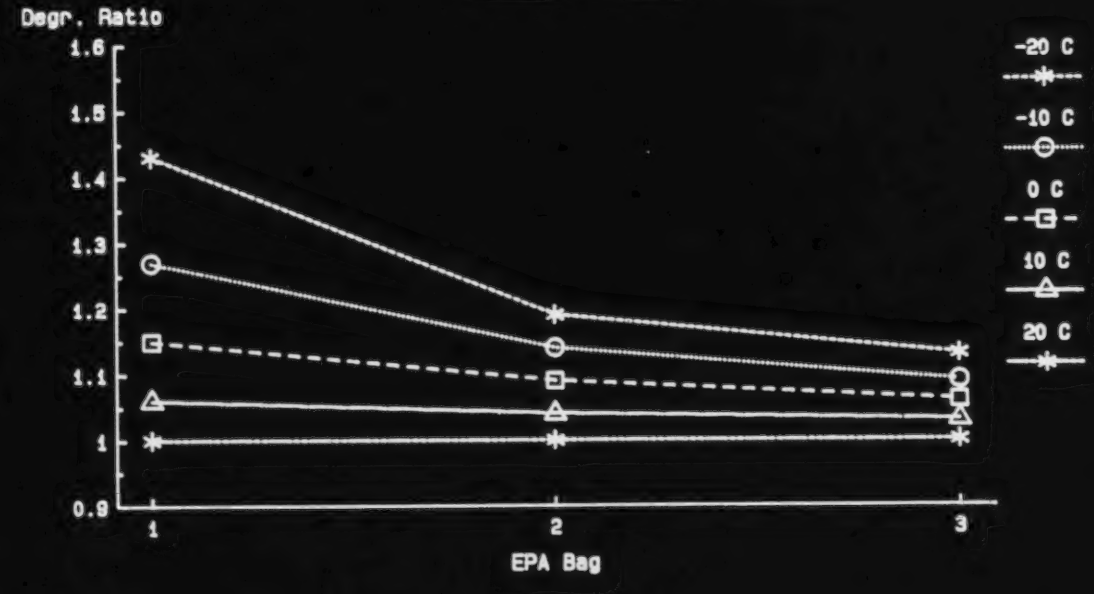


Figure 8b
Fuel Efficiency Degradation
(LTEP - TSD)



76-81 cars only

Table 7

Technologies vrs. Degradations

7.a Number of cylinders

		4 CYL	6CYL	8 CYL
% OF SAMPLE		55%	35%	10%
+10 C	BAG 1	1.17	1.12	1.29
	BAG 2	1.04	1.07	1.07
	BAG 3	1.07	1.02	1.09
-10 C	BAG 1	1.34	1.32	1.46
	BAG 2	1.07	1.09	1.03
	BAG 3	1.09	1.06	1.07

7.b Emissions Technology

		Closed Loop	Open Loop	Catalytic Converter
% OF SAMPLE		49%	16%	35%
+10 C	BAG 1	1.17	1.12	1.18
	BAG 2	1.02	1.02	1.12
	BAG 3	1.03	1.03	1.08
-10 C	BAG 1	1.39	1.29	1.31
	BAG 2	1.05	1.06	1.11
	BAG 3	1.07	1.09	1.08

7.c Induction Type

		Carb.	Fuel Injection
% OF SAMPLE		97%	3%
+10 C	BAG 1	1.17	1.16
	BAG 2	1.06	1.00
	BAG 3	1.05	1.02
-10 C	BAG 1	1.34	1.41
	BAG 2	1.08	1.03
	BAG 3	1.08	1.07

SAVINGS). Open and Closed loop technologies tend to improve degradation performance. Engines of the V8 configuration tend to have significantly higher degradations than the 4 or 6 cylinder equipped cars.

Since the fraction of the data which were represented by the various technologies were similar to the market penetration of these technologies in 1980-1981 the data was considered representative of the fleet when a sales weighted average was employed.

5.3 AVERAGE DEGRADATIONS

The final estimated degradations which were used to calculate the effect of ambient temperatures on gasoline demand are given as Table 8.

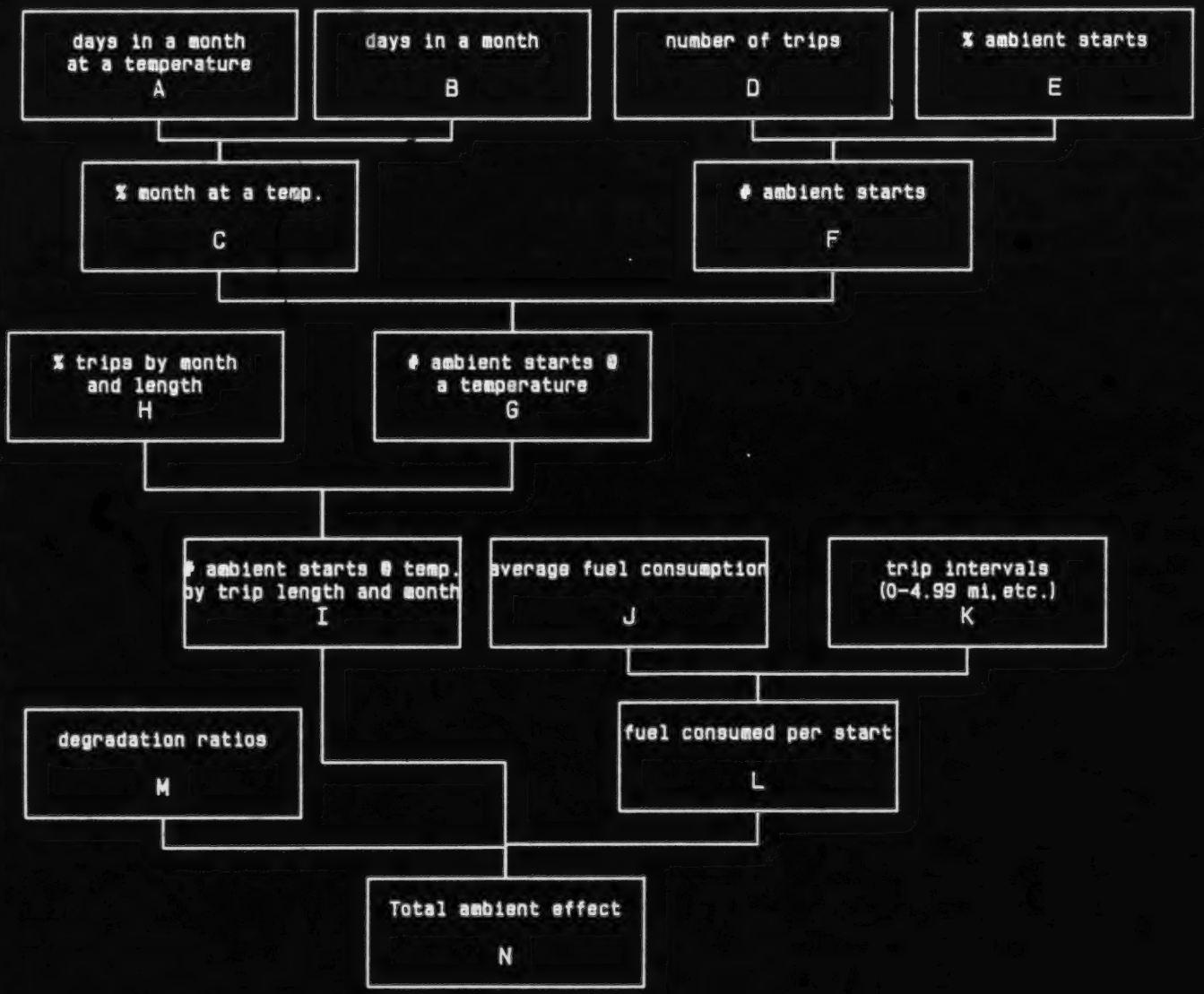
The degradations are largest immediately after vehicle start up (bag 1) and decrease with distance as engine and driveline temperatures reach operating temperatures. The degradations are largest for the colder ambient temperatures.

Table 8

Average Degradations

temperature	EPA bag	fuel consumption (l/100km)	degradation ratio
+20 C	1	11.44	1.00
	2	10.94	1.00
	3	9.52	1.00
+10 C	1	13.38	1.17
	2	11.49	1.05
	3	10.00	1.05
0 C	1	14.53	1.27
	2	12.03	1.10
	3	10.28	1.08
-10 C	1	15.44	1.35
	2	11.71	1.07
	3	10.28	1.08
-20 C	1	17.39	1.52
	2	13.89	1.27
	3	10.85	1.14

Figure 9
Flow Diagram of Calculations



6.0 TOTAL AMBIENT EFFECT

The total ambient effect on Canadian gasoline demand is the volume of gasoline which is used due to the operation of passenger cars in a degraded fuel efficiency condition because of cold ambient temperatures. The main result of this report is to calculate this volume.

To calculate the total ambient effect, the temperature, vehicle use, and degradation results are combined according to the scheme presented as Figure 9.

6.1 CALCULATION DETAILS

First, the Canadian average number of days at a given mean temperature in each month (A) is converted into the percentage of the month at that temperature, plus or minus 5°C, (B) by dividing it by the number of days in the respective month (B). February is always assumed to have 28 days.

Second, the number of trips (D) is multiplied by the percentage of starts which are ambient starts (E). This yields the number of ambient starts (F).

Third, the number of ambient starts in the month (F) is multiplied by the the percentage of the month that is at a given temperature (C) giving the number of ambient starts at a given mean temperature in each month (G).

Fourth, the distribution of trips by trip length and month (H) is used to find the number of trips of a given length which begin with an ambient start at each temperature (I). This is done by multiplication of the number of ambient starts (G) by the trip distribution (H).

Fifth, from the average fuel consumed for each trip distance (K), and the average degradation ratios at each temperature and distance (J), the amount of fuel consumed by the vehicle for each start (M) at each of the trip intervals (L) is calculated. (See Appendix 2 for details of the

Table 9
Total Ambient Effect at 60% A.S.

million litres

miles-->	0-4.99	5-8.99	9-12.99	>13	SUBTOTAL
J	12.67	9.25	5.24	13.82	40.98
F	10.06	6.78	5.18	12.98	35.00
M	12.06	8.01	6.10	13.49	39.66
A	7.42	5.94	4.08	10.59	28.05
M	5.96	5.11	4.10	9.33	24.51
J	1.33	1.08	0.74	2.11	5.25
J	0.23	0.21	0.13	0.29	0.86
A	0.35	0.31	0.21	0.67	1.53
S	3.70	2.75	2.00	5.82	14.27
O	7.53	6.31	4.31	10.42	28.58
N	8.97	7.99	5.15	13.01	35.13
D	9.94	7.29	5.07	13.68	35.98
				total =	289.80

Percent of total demand

miles-->	0-4.99	5-8.99	9-12.99	>13	SUBTOTAL
J	0.058%	0.042%	0.024%	0.063%	0.187%
F	0.046%	0.031%	0.024%	0.059%	0.160%
M	0.055%	0.037%	0.028%	0.062%	0.181%
A	0.034%	0.027%	0.019%	0.048%	0.128%
M	0.027%	0.023%	0.019%	0.043%	0.112%
J	0.006%	0.005%	0.003%	0.010%	0.024%
J	0.001%	0.001%	0.001%	0.001%	0.004%
A	0.002%	0.001%	0.001%	0.003%	0.007%
S	0.017%	0.013%	0.009%	0.027%	0.065%
O	0.034%	0.029%	0.020%	0.048%	0.131%
N	0.041%	0.036%	0.024%	0.059%	0.160%
D	0.045%	0.033%	0.023%	0.062%	0.164%
				total =	1.323%

fuel consumed calculations). The volume of fuel consumed due to the ambient effect is computed by substracting the fuel used at the reference temperature of 25°C from the amount of fuel used at a given ambient temperature.

Finally, the total amount of fuel due to ambient temperature effects is the sum of the fuel used because of the ambient temperature for each start, for each trip distance, for each month. The resulting number is the ambient temperature effect on Canadian gasoline demand (N).

6.2 TOTAL FUEL DEMAND

From EMR/TEB[3] an estimate of the total passenger car gasoline demand in Canada in 1981 is 22.2×10^9 litres. Because most of the data were circa 1981, this figure was used to determine the relative importance of the ambient effect.

6.3 AMBIENT EFFECT VOLUME

From the calculations presented above, the estimated ambient effect volume is 289.8 million litres/year (1,821,380 barrels per year or 11,140 terajoules); this is 1.323% of the total Canadian gasoline demand. The volumes are largest from November to March, when 186.7 million litres are used each year due to the ambient temperature fuel efficiency degradations. See Table 9 for the results of the calculations. These estimates have been derived with the assumption of 60% of the vehicle trips are ambient starts (see 4.2 AMBIENT START PERCENTAGE). If one wishes to assume a different level of ambient starts, it can be shown that the ambient effect volume varies linearly with the ambient start percentage (e.g. is 30% starts are assumed then the ambient effect volume would be 289.8/2 = 144.9 million litres, 0.91 million barrels/year).

3. Fuel Demand Evaluation Model, TEB.

Table 10
Degradation Histories

	degradation ratio				
	average	PRE-69	70-73	74-77	78-81
+20 C					
BAG 1	1.00	1.00	1.00	1.00	1.00
BAG 2	1.00	1.00	1.00	1.00	1.00
BAG 3	1.00	1.00	1.00	1.00	1.00
+10 C					
BAG 1	1.07	1.12	1.09	1.04	1.07
BAG 2	1.05	1.10	1.06	1.04	1.03
BAG 3	1.03	1.09	1.05	1.02	1.03
0 C					
BAG 1	1.15	1.25	1.20	1.11	1.16
BAG 2	1.10	1.22	1.13	1.09	1.05
BAG 3	1.07	1.19	1.11	1.04	1.05
-10 C					
BAG 1	1.27	1.40	1.36	1.20	1.27
BAG 2	1.15	1.36	1.20	1.14	1.08
BAG 3	1.11	1.30	1.17	1.05	1.08
-20 C					
BAG 1	1.44	1.58	1.59	1.33	1.43
BAG 2	1.21	1.53	1.27	1.19	1.11
BAG 3	1.15	1.42	1.24	1.07	1.11

Source: Low Temperature Effects Program

7.0 POTENTIAL SAVINGS

The potential for gasoline savings in Canada by legislated improvements in ambient start technologies is limited because of the small portion (1.323%) of the demand which is made up of ambient effects. In order to assess the possibilities, past trends and available technologies are examined.

7.1 HISTORICAL IMPROVEMENTS

Ambient start degradations improved significantly from the 1960s to the early 1980s without specific legislation on cold temperature technology. Due to the demand for increased fuel efficiency by both consumers and government, improved ambient start technology has been a by-product of general trends within the automotive industry.

Ambient degradation ratios have decreased by 20% between the 1960s and 1977. More recently, the degradation ratios have risen slightly (see Table 10). Though more study would be necessary to determine why, a reasonable explanation is that the amount of fuel used by a vehicle at cold soak conditions has decreased slightly while overall fuel consumption numbers have decreased to a larger extent.

7.2 RECENT TRENDS

Between the time the data was gathered for this report and the time it was written, several trends have appeared in the passenger car fleet which could affect the ambient temperature effect on Canadian gasoline demand. Two of these are the emergence of sophisticated electronic fuel injection devices, and the trend towards higher compression ratios made possible by electronic knock sensors and high swirl combustion technology.

Electronic fuel injection (EFI) allows the precise metering of gasoline to the engine so as to optimize its efficiency. Through sensors which detect the composition of the exhaust gases, a feedback loop can be used to allow for virtually any engine operating condition. While no

detailed study was available for these new EFI systems it is believed that they have significantly better cold start degradations than cars without EFI.

Fuel injected vehicles from the period around 1980 had smaller degradations than cars with carburetors from the same period. It is believed that with the application of complex electronic controls, as well as the trend towards port rather than throttle body injection, the ambient degradation ratios have decreased even further for fuel injected cars. Additional improvements may be possible by calibrating the electronic engine management systems which new cars are equipped with to optimize fuel consumption at 10°C, 0°C and -10°C. Manufacturer priority is generally to improve startability and driveability at low temperatures. Low temperature fuel consumption is of secondary importance but is believed to be improved indirectly as a result of driveability improvement.

Compression ratios have increased by approximately 1 pt during the 1980 to 1985 period. This has come about because of improved emmission control strategies and electronic control of the ignition timing which uses a knock sensor to detect detonation. The result has been to optimize the compression ratios for the fuel currently available. It will be shown in the next section that higher compression ratios tend to lower degradation ratios quite significantly. It is estimated that the trend towards increasing compression ratios has already reduced gasoline demand by about 0.050%.

7.3 POSSIBLE FUTURE IMPROVEMENTS

Manufacturers are currently working on several areas in which cold fuel consumption degradation improvements may be found. Improved lubricant technology and increased electronic fuel injection sophistication are areas in which manufacturers are currently working. While manufacturers' prime reason for investing in these technologies is to increase driveability and startability at cold temperatures, they believe fuel consumption will benefit from the application of such technologies.

To estimate the amount of fuel which could be saved due to legislated improvements in the ambient fuel degradation, an obtainable level of improvement must be determined.

7.3.1 TYPES OF LEGISLATION

Legislation could either require that certain equipment be used on new, and possibly older, cars; or it could require that new cars meet specific degradation ratio objectives.

Setting objectives rather than legislating the equipment of passenger cars would be much more difficult to administer since it would involve elaborate testing procedures. Equipment legislation would require only verification. Therefore only equipment legislation is considered feasible.

7.3.2 DEGRADATION IMPROVEMENT STUDIES

A study was performed by Chrysler Canada Co. to determine the improvements in vehicle fuel consumption which occur with the application of five types of ambient start technologies. The five technologies are: block heat conservation, early fuel evaporation, automatic idle speed, optimum cold start timing, and high compression ratio.

The block heat conservation configuration involves insulating the vehicles engine block with 12mm of insulating foam, as well as restricting the airflow though the engine compartment. The early fuel evaporation configuration has an electrically heated honeycomb in the airflow path between the carburetor and intake manifold, in addition to a more effective heat stove and a higher activity, lower torque choke coil. The automatic idle speed configuration uses a linear action motor (LAM) to replace the throttle stop at both fast idle and curb idle. The LAM is computer controlled and provides precise control of engine speeds during warm-up. The optimum cold timing strategy uses a temperature sensor and a computer to switch between two spark timing modes, cold and warm. The high compression ratio configuration uses pop-up pistons to increase the compression from 8.2:1 to 9.5:1 as well as a recalibrated spark advance curve.

Table 11
Degradation Technology Improvements

Configuration	percent improvement +25 C bag 1	+25 C bag2	+25 C bag3	+0 C bag 1	+0 C bag2	+0 C bag3	-20 C bag 1	-20 C bag2	-20 C bag3	estimated improvement in total demand *
high compression ratio	+7.2	+5.1	+6.1	+8.5	+4.2	+1.3	+6.5	+5.0	+4.3	0.039%
automatic idle speed	+0.6	-2.0	-0.8	+1.9	-4.5	-1.2	+12	-3.2	+3.3	0.001%
early fuel evaporation	-5.8	-4.9	-2.4	+13	-3.8	-3.2	+18	-0.4	+0.3	0.011%
optimum cold timing	+4.8	-1.4	+1.3	+3.9	+0.5	+0.2	+15	-1.6	0.0	0.017%
block heat conservation	-3.6	-1.0	+1.6	-	-	-	+5.8	+4.1	+7.8	0.010%

* Assuming 100% new and used fleet penetration of each technology

Each of the above configurations were tested at +25°C, 0°C, and -20°C. The percent improvement in ambient temperature fuel efficiency at the test temperatures by EPA bag are given in Table 11. Included with Table 11 are estimates of the net effect of these technologies on the demand for gasoline.

In the Chrysler study, only two non-standard test temperature data points were available, and the intermediate degradations were unknown. The degradation ratios for 0°C were also applied to the temperature of 10°C, and the degradation ratios for -20°C were also applied to the -10°C temperature. Since degradations tend to increase with lower temperatures, the results given in Table 11 tend to over-estimate the amount of fuel which could be saved.

Some of these technologies would have a larger overall effect than given in Table 11, since they increase efficiency in situations other than cold temperature soaks. The high compression ratios would show this effect most.

As noted in 7.2 RECENT TRENDS, some of the technologies given in the Chrysler study have already begun to penetrate the market. Higher compression ratios, optimum timing and automatic idle speed control are being incorporated into the electronic engine management systems which manufacturers are introducing. Further increases in compression ratios or timing advances are unlikely without higher quality gasoline. This higher quality gasoline will mean fewer litres of gasoline can be extracted from a barrel of oil, and further study will have to be done to find if the increase in fuel consumption can offset the decrease in supply.

As well, some technologies are unlikely to be offered on new cars. The block heat conservation is an example, which would probably not be introduced as it would interfere with the servicability of some engine components, and it decreases "warm" fuel efficiency.

7.4 EFFECT ON DEMAND

The fuel consumption degradation ratios from the Chrysler study are processed according to the scheme presented in 6.0, CALCULATION METHODOLOGY. The most effective of the technologies is the high compression ratio strategy, and it is significant to note that in the 5 years since that study the manufacturers have moved to adopt some of the technologies then being processed.

Manufacturers have stated that they expect degradations to continue to decline as better electronics, lubricants, and other technologies are developed.

The adoption of these new technologies has occurred without specific legislation of ambient start degradations. It is believed that market pressures from consumers and government fuel efficiency guidelines (CAFC) have influenced manufacturers to build efficient motor vehicles. A by-product of this trend is improvement of ambient start fuel economy. This study concludes that the effect of specific legislation on Canadian gasoline demand would be small.

Perhaps the most effective strategy for reducing cold start degradations could be for manufacturers to equip all new cars with timed block heater devices. Also, manufacturers might be encouraged to have optimized electronic engine management schemes for the significant ambient temperature range of -10°C to 20°C.

APPENDIX 1
Temperature Distributions
Number of days at
-30C

	J	F	M	A	M	J	J	A	S	O	N	D
TORONTO	0	0	0	0	0	0	0	0	0	0	0	0
MONTREAL	0	0	0	0	0	0	0	0	0	0	0	0
VANCOUVER	0	0	0	0	0	0	0	0	0	0	0	0
OTTAWA-HULL	0	0	0	0	0	0	0	0	0	0	0	0
EDMONTON	0.5	0	0	0	0	0	0	0	0	0	0	0
CALGARY	0.1	0	0	0	0	0	0	0	0	0	0	0
WINNIPEG	1.0	0	0	0	0	0	0	0	0	0	0	0
QUEBEC CITY	0	0	0	0	0	0	0	0	0	0	0	0
HAMILTON	0	0	0	0	0	0	0	0	0	0	0	0
ST. CATHERINES	0	0	0	0	0	0	0	0	0	0	0	0
KITCHENER	0	0	0	0	0	0	0	0	0	0	0	0
LONDON	0	0	0	0	0	0	0	0	0	0	0	0
HALIFAX	0	0	0	0	0	0	0	0	0	0	0	0
WINDSOR	0	0	0	0	0	0	0	0	0	0	0	0
VICTORIA	0	0	0	0	0	0	0	0	0	0	0	0
REGINA	1.3	0	0	0	0	0	0	0	0	0	0	0
ST. JOHN'S	0	0	0	0	0	0	0	0	0	0	0	0
OSHAWA	0	0	0	0	0	0	0	0	0	0	0	0
SASKATOON	2.4	0.1	0	0	0	0	0	0	0	0	0	0.3
SUDBURY	0	0	0	0	0	0	0	0	0	0	0	0
CHICOUTIMI	0	0	0	0	0	0	0	0	0	0	0	0
THUNDER BAY	0	0	0	0	0	0	0	0	0	0	0	0

-20C

	J	F	M	A	M	J	J	A	S	O	N	D
TORONTO	0	0	0	0	0	0	0	0	0	0	0	0
MONTREAL	0.5	0.1	0	0	0	0	0	0	0	0	0	0
VANCOUVER	0	0	0	0	0	0	0	0	0	0	0	0
OTTAWA-HULL	1.6	0.4	0	0	0	0	0	0	0	0	0	0.1
EDMONTON	15.0	2.9	0	0	0	0	0	0	0	0	0.1	4.7
CALGARY	7.7	1.0	0	0	0	0	0	0	0	0	0	1.6
WINNIPEG	27.4	15.6	0.6	0	0	0	0	0	0	0	0	11.8
QUEBEC CITY	3.9	1.9	0	0	0	0	0	0	0	0	0	0.3
HAMILTON	0	0	0	0	0	0	0	0	0	0	0	0
ST. CATHERINES	0	0	0	0	0	0	0	0	0	0	0	0
KITCHENER	0	0	0	0	0	0	0	0	0	0	0	0
LONDON	0	0	0	0	0	0	0	0	0	0	0	0
HALIFAX	0	0	0	0	0	0	0	0	0	0	0	0
WINDSOR	0	0	0	0	0	0	0	0	0	0	0	0
VICTORIA	0	0	0	0	0	0	0	0	0	0	0	0
REGINA	22.3	9.6	0	0	0	0	0	0	0	0	0	8.8
ST. JOHN'S	0	0	0	0	0	0	0	0	0	0	0	0
OSHAWA	0	0	0	0	0	0	0	0	0	0	0	0
SASKATOON	24.2	12.2	0.7	0	0	0	0	0	0	0	0.1	12.8
SUDBURY	9.1	4.7	0	0	0	0	0	0	0	0	0	1.0
CHICOUTIMI	14.3	6.8	0	0	0	0	0	0	0	0	0	1.6
THUNDER BAY	16.6	8.8	0	0	0	0	0	0	0	0	0	3.0

-10C

	J	F	M	A	M	J	J	A	S	O	N	D
TORONTO	13.1	8.8	0	0	0	0	0	0	0	0	0	1.4
MONTREAL	28.6	26.9	3.9	0	0	0	0	0	0	0	0	22.3
VANCOUVER	0	0	0	0	0	0	0	0	0	0	0	0
OTTAWA-HULL	29.2	26.6	5.6	0	0	0	0	0	0	0	0	25.7
EDMONTON	15.0	21.1	15.5	0	0	0	0	0	0	0	11.1	22.9
CALGARY	20.8	18.7	11.7	0	0	0	0	0	0	0	8.2	21.3
WINNIPEG	2.6	11.7	23.4	0	0	0	0	0	0	0	12.1	19.1
QUEBEC CITY	27.8	25.6	12.5	0	0	0	0	0	0	0	0.1	28.8
HAMILTON	13.4	8.6	0	0	0	0	0	0	0	0	0	0.9
ST. CATHERINES	13.7	10.3	0	0	0	0	0	0	0	0	0	2.5
KITCHENER	24.7	18.4	1.2	0	0	0	0	0	0	0	0	9.2
LONDON	23.2	18.6	1.0	0	0	0	0	0	0	0	0	7.6
HALIFAX	10.5	11.0	0	0	0	0	0	0	0	0	0	2.2
WINDSOR	15.0	6.4	0	0	0	0	0	0	0	0	0	2.4
VICTORIA	0	0	0	0	0	0	0	0	0	0	0	0
REGINA	7.4	17.7	21.6	0	0	0	0	0	0	0	15.0	21.4
ST. JOHN'S	8.4	11.5	2.7	0	0	0	0	0	0	0	0	2.1
OSHAWA	8.4	11.5	2.7	0	0	0	0	0	0	0	0	4.2
SASKATOON	4.4	15.0	23.9	0	0	0	0	0	0	0	17.2	17.0
SUDBURY	21.9	23.3	20.7	0	0	0	0	0		0	0.9	29.3
CHICOUTIMI	16.7	21.4	16.9	0	0	0	0	0	0	0	0.3	28.8
THUNDER BAY	14.2	21.1	21.7	0	0	0	0	0	0	0	3.4	27.4

0C

	J	F	M	A	M	J	J	A	S	O	N	D
TORONTO	17.9	19.2	30.7	1.3	0	0	0	0	0	0	15.6	29.6
MONTREAL	0.6	1.0	27.1	8.4	0	0	0	0	0	0.5	28.7	7.4
VANCOUVER	26.1	17.1	8.8	0	0	0	0	0	0	0	8.4	23.3
OTTAWA-HULL	0.3	1.0	25.4	10.0	0	0	0	0	0	0.9	29.5	5.2
EDMONTON	0.5	4.0	15.5	19.1	0	0	0	0	0	10.0	18.4.	3.6
CALGARY	2.4	8.2	19.2	0	0	0	0	0	0	12.8	21.2	8.1
WINNIPEG	0	0	6.4	0	0	0	0	0	0	7.4	17.8	0.1
QUEBEC CITY	0	0.5	18.4	0	0	0	0	0	0	3.4	30.1	1.9
HAMILTON	17.6	19.4	30.6	0	0	0	0	0	0	0	15.7	30.0
ST. CATHERINES	17.3	17.7	31.0	0	0	0	0	0	0	0	20.2	28.4
KITCHENER	6.3	9.6	29.7	0	0	0	0	0	0	0.3	26.4	21.8
LONDON	7.8	9.4	29.9	0	0	0	0	0	0	0.2	26.2	23.4
HALIFAX	20.5	16.9	31.1	0	0	0	0	0	0	0	18.5	28.7
WINDSOR	16.0	19.6	30.1	0	0	0	0	0	0	0	19.5	28.5
VICTORIA	22.3	7.2	2.1	0	0	0	0	0	0	0	0.9	12.4
REGINA	0	0.3	7.8	0	0	0	0	0	0	13.8	14.6	0.7
ST. JOHN'S	22.6	16.5	28.3	0	0	0	0	0	0	0.8	25.1	28.8
OSHAWA	12.7	14.5	30.3	0	0	0	0	0	0	0.2	23.1	26.8
SASKATOON	0	0.2	5.5	0	0	0	0	0	0	18.0	12.8	0.8
SUDBURY	0	0.1	10.2	0	0	0	0	0	0	8.2	29.1	0.7
CHICOUTIMI	0	0.1	14.1	0	0	0	0	0	0	4.8	29.7	0.8
THUNDER BAY	0	0.1	9.3	0	0	0	0	0	0	10.7	26.6	0.7

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10C

	J	F	M	A	M	J	J	A	S	O	N	D
TORONTO	0	0	0.3	26.7	24.4	0	0	0	1.7	30.7	29.7	0
MONTREAL	0	0	0	21.3	25.8	0.1	0	0	18.5	30.4	29.4	0
VANCOUVER	2.9	10.5	24.0	26.9	29.0	13.2	0.7	0.8	22.3	38.3	37.0	7.4
OTTAWA-HULL	0	0	0	19.8	26.9	0.3	0	0	20.9	30.0	29.0	0
EDMONTON	0	0	0	10.9	30.4	13.5	0.6	7.7	28.9	20.9	20.3	0
CALGARY	0	0.1	0.1	7.7	31.1	25.7	2.8	13.9	29.1	18.2	17.6	0.1
WINNIPEG	0	0	0	8.3	27.1	3.4	0.1	0.8	27.1	23.7	22.9	0
QUEBEC CITY	0	0	0	0.5	31.0	4.6	0	1.2	28.4	28.6	27.7	0
HAMILTON	0	0	0.4	28.9	23.2	0	0	0	1.0	30.6	29.7	0
ST. CATHERINES	0	0	0.1	26.4	29.0	0.1	0	0	4.2	32.5	31.5	0.1
KITCHENER	0	0	0	23.6	27.5	0.3	0	0	9.6	30.7	29.7	0
LONDON	0	0	0.1	24.1	28.4	0.5	0	0	11.2	30.8	29.8	0
HALIFAX	0	0	0	5.8	29.3	30.2	0.6	0.1	19.5	33.8	32.7	0.1
WINDSOR	0	0	0.9	29.1	20.9	0	0	0	1.1	30.5	29.5	0
VICTORIA	8.7	20.8	31.3	28.5	27.9	29.7	8.8	9.7	23.6	29.6	28.6	18.0
REGINA	0	0	0	8.3	30.5	8.4	0.1	1.9	28.7	17.0	16.4	0
ST. JOHN'S	0	0	0	0.2	22.0	29.2	11.3	11.1	23.5	32.7	31.6	0.1
OSHAWA	0	0	0.3	26.7	30.0	1.1	0	0	5.0	30.7	29.7	0
SASKATOON	0	0	0	8.30	30.5	10.3	0.1	2.2	29.6	15.0	14.5	0
SUDBURY	0	0	0	1.6	30.5	5.8	0	2.3	28.9	22.8	22.0	0
CHICOUTIMI	0	0	0	2.2	30.9	4.1	0.1	0.8	28.9	28.8	25.3	0
THUNDER BAY	0	0	0	1.2	30.5	25.4	0.4	4.8	29.5	20.3	19.6	0

20C

	J	F	M	A	M	J	J	A	S	O	N	D
TORONTO	0	0	0	0	6.7	29.8	28.2	30.3	29.0	0.2	0.2	0
MONTREAL	0	0	0	0	5.2	28.4	30.8	31.7	19.1	0	0	0
VANCOUVER	0	0	0	0	0.1	15.2	31.2	32.7	8.1	0	0	0
OTTAWA-HULL	0	0	0	0	4.2	26.5	31.7	31.0	8.9	0	0	0
EDMONTON	0	0	0	0	0.2	15.5	30.9	23.3	1.0	0	0	0
CALGARY	0	0	0	0	0	4.6	31.3	16.9	0.7	0	0	0
WINNIPEG	0	0	0	0	3.4	27.0	31.1	30.0	2.9	0	0	0
QUEBEC CITY	0	0	0	0	0.1	25.9	30.8	29.8	1.7	0	0	0
HAMILTON	0	0	0	0	7.8	29.8	24.7	29.5	30.6	0.3	0.3	0
ST. CATHERINES	0	0	0	0	2.1	28.5	30.5	31.4	26.2	0	0	0
KITCHENER	0	0	0	0	3.5	28.8	31.4	31.8	20.1	0.1	0.1	0
LONDON	0	0	0	0	2.6	28.9	32.3	31.6	18.3	0	0	0
HALIFAX	0	0	0	0	0	2.8	30.9	28.3	8.4	0	0	0
WINDSOR	0	0	0	0	10.0	30.8	29.5	29.7	29.1	0.5	0.5	0
VICTORIA	0	0	0	0	0.1	3.2	17.3	14.7	6.1	0	0	0
REGINA	0	0	0	0	0.5	21.6	30.5	29.1	1.2	0	0	0
ST. JOHN'S	0	0	0	0	0	0.8	19.6	19.6	0	0	0	0
OSHAWA	0	0	0	0	0.9	29.1	39.1	32.5	25.4	0.1	0.1	0
SASKATOON	0	0	0	0	0.1	19.6	29.4	29.0	0.3	0	0	0
SUDBURY	0	0	0	0	0.4	24.6	29.1	28.8	0.8	0	0	0
CHICOUTIMI	0	0	0	0	0.1	26.7	30.8	30.5	0.9	0	0	0
THUNDER BAY	0	0	0	0	0	5.3	30.2	26.8	0.1	0	0	0

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APPENDIX 2

In assigning fuel amounts to trips, average trip lengths are used. For example, trips in the 0-4.99 mile interval are all asssumed to have travelled the average 0-4.99 distance of 2.50 miles and assigned a volume of gasoline used of ($2.50/4.99_{*}$ bag 1 vol.). The average trip distance for each trip interval is obtained by dividing the trip interval mileage by the trip interval frequency. Trips travelling 5-8.99 miles receive the full 0-4.99 volume of gasoline plus the amount ($(7.00-4.99)_{*}$bag2 vol.). The 9-12.99 trips receive the full 0-4.99 volume, plus the full 5-8.99 volume, plus the amount ($(11.00-8.99)_{*}$bag 3 vol.). Trips over 13 miles receive the full volume of each of the bags plus a weighted volume, which is dependent on the average trip length for trips over 13 miles, of ((15.00-12.99)bag 3 volume). The trips over 13 miles are thus assumed to have constant fuel efficiency at the bag 3 level. In practice, one would expect the fuel efficiency to increase with increasing distance since the engine would reach operating temperatures conducive to higher fuel efficiency. By making the assumption of constant fuel efficiency, this report will overestimate the effect of ambient temperatures on Canadian gasoline demand.